Calibrating two scientific echo sounders

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Abstract- **The Simrad EK500 has been the state-of-the-art scientific echo sounder for surveying marine fish stocks; the EK60 is its successor. Both echo sounders have been calibrated with the same 38-kHz, 12-deg-beamwidth, split-beam transducer by the standard-target method at the acoustic calibration facility on Iselin Dock at the Woods Hole Oceanographic Institution. The principal measurements were on-axis target strengths and the two-way directivity patterns of the main lobe, measured with a 60-mm-diameter copper sphere. For each echo sounder, the respective split-beam-determined and directly measured angles of the standard target are compared. The directivity pattern as approximated by Simrad firmware is fit to the experimental data, and both the split-beam-determined and newly compensated values of target strength are expressed through histograms. Target strength distributions are compared for two spheres: a 60-mm-diameter aluminum and 38.1-mm-diameter tungsten carbide with 6% cobalt binder spheres.**

I INTRODUCTION

Calibration of scientific echo sounders is a fundamental and necessary component for maintaining high-quality numerical density and abundance estimates of marine organisms and for comparability among echo sounders and surveys [1], [2]. Standard target calibrations are a convenient method to measure system stability and to calibrate echo sounder systems (transmitter, receiver, and transducer) to an absolute standard [3], [4].

The Simrad[**] EK500 scientific echo sounder [5] is a standard echo sounder used for fisheries applications throughout the world. The Simrad EK60 scientific echo sounder is the next-generation system. These two systems must be calibrated in order to be used in quantitative fisheries applications. This is the subject of the present paper.

In this paper, on-axis and beam pattern measurements using the standard target calibration method were conducted using 38-kHz EK500 and EK60 echo sounders. In a companion paper [6], the performance of the two systems will be compared.

II METHODS

Acoustic backscatter data were collected with a Simrad EK500 scientific echo sounder and a Simrad EK60 scientific echo sounder, each operating at 38 kHz during 6-7 January 2003. Experiments were conducted at the calibration facility on the Iselin Dock at the Woods Hole Oceanographic Institution [7]. The echo sounders shared the same 38-kHz split-beam transducer, Simrad model number ES38-12, by means of a multiplexing junction box (Fig. 1). The beamwidth of this transducer was 12^{o} (measured as the total angular distance between the half power points). The transducer was mounted looking sideways on a 6-m shaft suspended at a water depth of approximately 3 m. The shaft was secured within a section of antennae tower and attached to a computer-controlled rotation mechanism. The personal computer (PC) controlled rotational parameters such as beginning and ending degree of rotation, rotation increment, speed of rotation, and the number of pings per rotation increment [7]. For each rotation increment, the EK500 and EK60 were alternately 'triggered' at a rate of 2-pings per second (one-ping per second for each echo sounder). The trigger generator was connected to each echo sounder and to a set of mechanical relays in the transducer junction box. The relays were coordinated to synchronize transmit and receive signals to the transducer for each echo sounder. The EK500 and EK60 transmit data via Ethernet connections to a PC for analysis.

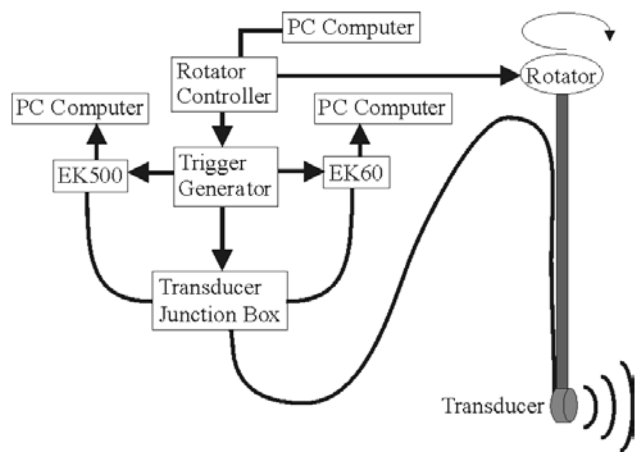

Figure 1. Schematic of EK500 and EK60 experimental setup. The transducer shaft was approximately 6-m long and the sideways looking transducer was placed approximately 3 m below the water surface. The figure is not drawn to scale.

Operation of both echo sounders was software-controlled through selection of parameter values. Operational parameters were: 1-ms pulse duration, wide bandwidth (~10% of the center frequency = 3.8 kHz), time-varied gain (TVG) of $40\log_{10}(r)$, where r is range, and 10 dB km^{-1} attenuation coefficient. These operational parameters were chosen as they are used for surveys conducted at the Northeast Fisheries Science Center [8]. The EK500 and EK60 detect individual targets based on the amplitude and width of the echo [5], [9]. Single-target detection parameters were: -54 dB threshold, 6 dB maximum compensation, and a maximum phase deviation of 4 phase steps (the EK500 has 64 phase steps per 180 electrical degrees, and the EK60 has 128 phase steps per 180 electrical degrees). Minimum and maximum echo width parameters were set to 0.6 and 1.5 respectively, where echo width is measured relative to the transmit pulse width. The EK500 and EK60 compute the angular location of single targets based on electrical phase differences among the quadrants of the split-beam transducer.

The transducer was mounted facing sideways with the alongship axis oriented vertically (positive angles up) and the

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athwartship angles oriented horizontally (positive angles to the right). Two general sets of measurements were obtained: on-axis measurements, and transducer beam directivity response. A 60-mm-diameter copper calibration sphere [10] suspended with a monofilament line was used as the standard target. For on-axis measurements, the sphere was positioned on the geometric axis of the transducer by measuring the depth of the transducer and aligning the sphere on the athwartship axis with a laser mounted on the rotator, which was perpendicular to the transducer face. The sphere was placed at a range of approximately 11.5 m from the transducer. At this range, 20 cm subtends an arc of 1-degree. The transducer's directivity was measured by rotating the transducer (horizontal, 'athwartship' angles) and raising and lowering the sphere (vertical, 'alongship' angles). Athwartship angles ranged from -15^o to $+15^o$ in 0.5^o increments (a 'sweep'). Alongship angles ranged from -9^o to $+9^o$ in 1-degree increments. One echo time series was collected at each angle for each echo sounder. A horizontal sweep was completed at each alongship angle with three sweeps at 0^o (the first and last sweep, and between measurements of the upper and lower quadrants) for a total of 21 sweeps.

EK500 and EK60 data were imported to SonarData's Echoview acoustic postprocessing software [11] for analysis. Data were displayed as echograms, and echoes from the calibration spheres were visually selected. Values exported from Echoview were the range, echo strength ('uncompensated' target strength), 'compensated', split-beam target strength, and alongship and athwartship angles for single-target detections of the calibration sphere.

On-axis measurements consisted of 1000 pings per echo sounder to evaluate the on-axis sensitivity and time-based stability of echo amplitudes and angular locations derived by each echo sounder.

Transducer beam pattern measurements consisted of echo sounder derived target locations relative to the expected angles (expected angles are based on the geometry of the experimental apparatus). The measured directivity response of the acoustic beam was compared to the directivity defined by the Simrad processing software, based on [12].

The EK500 uses a small-angle approximation to define the beam directivity as

$$TS_{comp}(\alpha,\beta) = 6.0206\left[\left(\frac{2\alpha}{BW_\alpha}\right)^2 + \left(\frac{2\beta}{BW_\beta}\right)^2 - 0.18\left(\frac{2\alpha}{BW_\alpha}\right)^2 \bullet \left(\frac{2\beta}{BW_\beta}\right)^2\right] \qquad (1)$$

where α is the measured alongship angle, β is the measured athwartship angle, BW_α is the total angular beamwidth (measured at the half-power points) in the alongship direction, and BW_β is the total athwartship angular beamwidth. BW_α and BW_β are 12^o for the 38-kHz transducer. Equation (1) is used to compensate echo strength measurements for angular location in the acoustic beam

An empirical directivity was derived by fitting a second order polynomial to the alongship and athwartship angles and echo strength measurements. The form of the polynomial is:

$$TS_{comp}(\alpha,\beta) = TS_{const} + c_0\alpha + c_1\alpha^2 + c_2\beta + c_3\beta^2 \qquad (2)$$

where TS_{const} is the overall echo strength compensation value and c_0, c_1, c_2, and c_3 are the empirically determined coefficients.

III RESULTS AND DISCUSSION

Target Strength Variability

The 60-mm copper calibration sphere was placed on the geometric axis of the transducer (0^o alongship and 0^o athwartship), and 1000 transmissions per echo sounder were collected to evaluate the on-axis sensitivity and time-based stability of echo amplitude measurements. Echo strengths were compensated using (1) to give 'compensated', split-beam target strengths (TS) of the sphere. Split-beam target strengths from both echo sounders showed a slight oscillatory trend over time where TS from the EK500 increased by about 0.5 dB approximately 5 minutes into the trial, and TS from the EK60 oscillated by about 0.5 dB over the course of the trials (upper panels, Fig. 2). Over the set of measurements, split-beam target strengths varied approximately 1 dB for the EK500 and about 1.5 dB for the EK60.

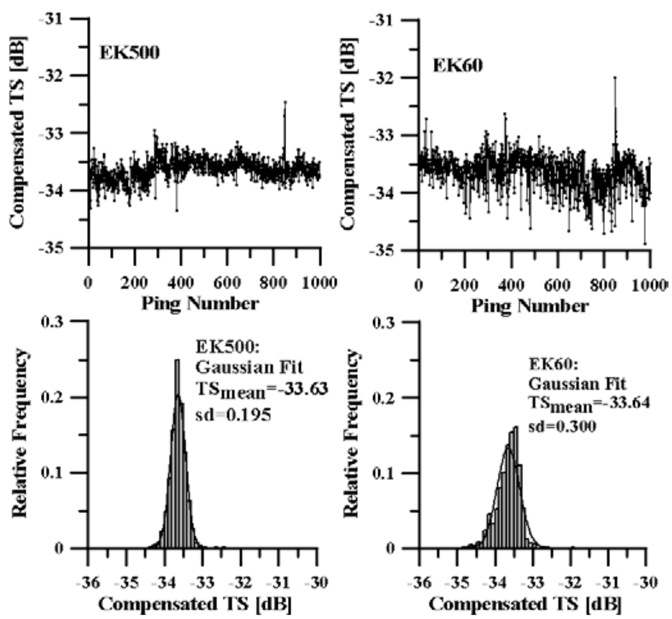

Figure 2. Time series (upper panels) and frequency histograms (lower panels) of on-axis echo amplitude measurements of a 60-mm-diameter copper sphere for the EK500 and EK60. Ping rate was 1 ping s^{-1} per echo sounder and 1000 pings represents approximately 17 minutes. Echo strength measurements were compensated for location in the acoustic beam. Mean split-beam target strength (TS) and standard deviation (sd) are derived from the Gaussian fit to the data.

Mean split-beam target strengths were -33.63 dB for the EK500 and -33.64 dB for the EK60, and TS distributions were unimodal for the EK500 and EK60 (lower panels, Fig. 2). A Gaussian fit of the EK500 and EK60 target strength distribution resulted in a standard deviation of 0.2 dB for the EK500 and 0.3 dB for the EK60 data. The EK60 target strength distribution was slightly skewed towards greater TS values.

Angular Position Variability

Based on the geometry of the transducer mounting, the calibration sphere was aligned on the geometric axis of the transducer. Observations of the alongship (vertical) and athwartship (horizontal) angular locations of the sphere show that it was closely aligned with the alongship axis but not with the athwartship axis (Fig. 3). The mean alongship angles were -0.08^{o} for the EK500 and -0.14^{o} for the EK60. The mean athwartship angles were -0.62^{o} for the EK500 and -0.71^{o} for the EK60. The difference between EK500 and EK60 mean alongship angles are within the angular resolution of both echo sounders (0.225^{o} for the EK500, and 0.1125^{o} for the EK60). The difference between the mean EK500 and EK60 athwartship angles and the axis (0.6-0.7^{o}) is greater than the angular resolution, and is indicative of an offset in the experimental apparatus or the angular locations derived by the echo sounders.

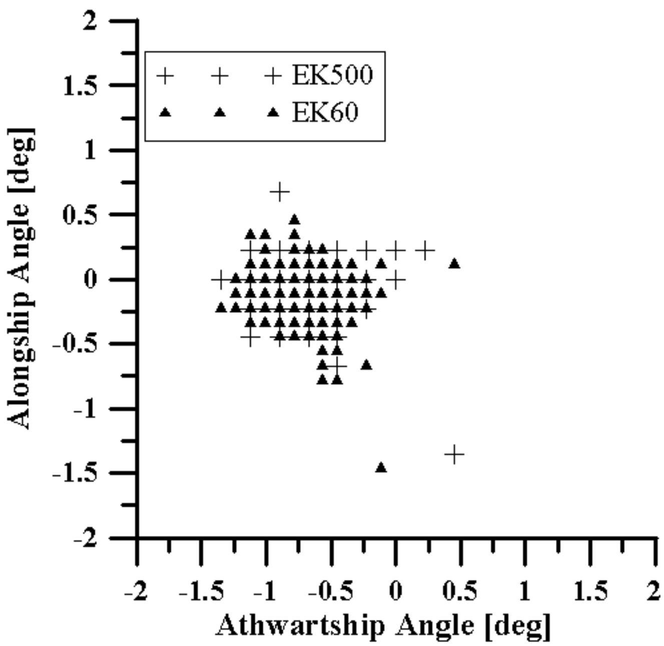

Figure 3. On-axis angular locations for the 60-mm copper sphere single target detections for 1000 pings. Triangles denote the EK60 single target angular locations and "+" symbols denote EK500 single target angular locations.

Beam Pattern Measurements

Beam pattern measurements were conducted to assess the transducer directivity response relative to the expected directivity based on the experimental geometry and the Simrad defined directivity. The expected transducer directivity was calculated using the Simrad directivity (equation (1)) and the expected alongship and athwartship angles based on the geometrical relationship of the transducer and 60-mm copper calibration sphere. The observed transducer directivity was based on the echo strength and angle location derived for each single target detection. Differences between the expected and the observed directivities were computed by subtracting the observed compensated target strengths from the expected compensated target strengths for each angular location:

$$\Delta TS(\alpha,\beta) = TS_{\exp}(\alpha,\beta) - TS_{obs}(a,\beta) \qquad (3)$$

In general, positive differences between the expected and observed target strengths occurred at negative athwartship angles while negative differences occurred at positive athwartship angles (Fig. 4).

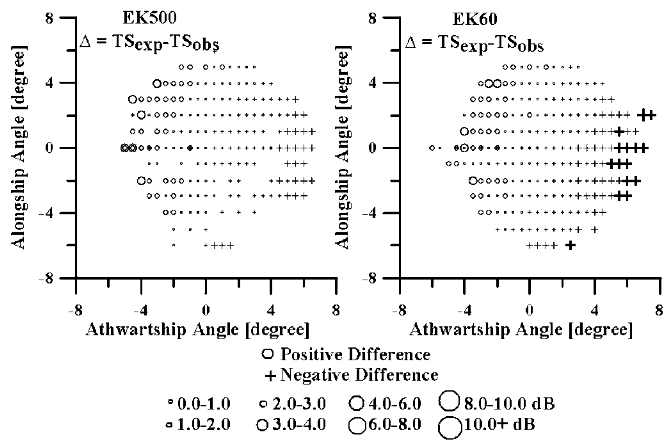

Figure 4. Difference between echo sounder directivity (equation (1)) based on expected along- and athwartship angles and observed split-beam target strength values for the EK500 (left panel) and EK60 (right panel) for the 60-mm copper sphere. Positive differences tend to be on the left (negative angles), while negative differences tend to be on the right (positive angles) indicating an offset between echo sounder derived angles and geometry based angles. Gaps in the measured beam pattern indicate that the calibration sphere was not detected as a single target for that angular location.

Both on-axis and beam pattern measurements indicated an athwartship offset (Figs. 3 and 4). Linear regressions were computed between expected and observed alongship and athwartship angles for the EK500 and EK60 beam pattern measurements (Fig. 5). Slopes of the linear regressions were near 1 for the alongship (1.061 for the EK500 and 1.080 for the EK60) and athwartship (1.017 for the EK500 and 1.018 for the EK60) angles. Intercepts were 0.114 (EK500) and 0.060 (EK60) for alongship angles. As in the on-axis measurements, alongship intercepts were within the angular resolution for each echo sounder. Athwartship intercepts were –0.860 (EK500) and –0.868 (EK60), indicating an athwartship angle offset.

Table 1. Sphere type, time, experimental trial, and tidal stage. These measurements were conducted on 7 January 2003. Sphere types are: 60-mm-diameter copper (CU60), 60-mm-diameter aluminum (AL60), and 38.1-mm-diameter tungsten carbide with 6% cobalt binder (WC381). Values in parentheses indicate the number of hours after the start of flood or ebb tide that the measurements were taken. The tides at Iselin Dock are semi-diurnal.

Sphere	Time (EST)	Trial	Tide Stage
CU60	1040-1215	Beam pattern	Flood (+4 to +6)
CU60	1220-1240	On-axis	Flood (+6)
WC381	1540-1600	On-axis	Ebb (+2)
AL60	1640-1650	On-axis	Ebb (+3)

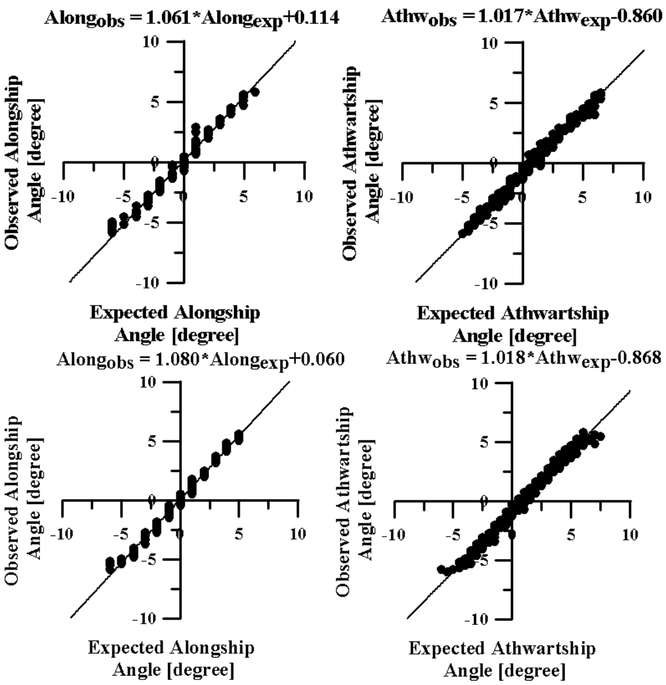

Figure 5. Expected (based on experimental geometry) versus observed (echo sounder derived) alongship (left side) and athwartship (right side) angles for the EK500 (upper panel) and the EK60 (lower panel). The linear regression between expected and observed is displayed.

The cause of the offset in the athwartship direction between the geometric axis and acoustic axis is uncertain at this time. This discrepancy could be due to inaccurate geometry measurements, inaccurate computation of the angular locations, environmental conditions such as tidal currents or temperature and salinity discontinuities, or a combination of all factors.

To investigate the possibility that the angular offsets were sphere-related, on-axis measurements were conducted with other sphere types (Table 1). On-axis measurements for a 60-mm-diameter aluminum sphere, and a 38.1-mm-diameter tungsten carbide sphere with 6% cobalt binder are presented. Similar to the copper sphere, EK500 split-beam target strengths were less variable than the EK60 split-beam target strengths for the aluminum (Figure 6) and tungsten carbide (Figure 7) spheres. Split-beam target strengths from the EK500 varied about 1 dB for the aluminum sphere and 1-1.5 dB for the tungsten carbide sphere. Target strengths from the EK60 varied approximately 1.5 dB for the aluminum sphere and >2 dB for the tungsten carbide sphere.

Mean alongship angles ranged from -0.18^o to 0.08^o and are within or near the angular resolution of the echo sounders. Mean athwartship angles ranged from -0.63^o to -0.69^o and are also indicative of an athwartship offset.

The tidal stage when the measurements were conducted is indicated in Table 1. The copper sphere beam pattern measurements were done during mid-flood tide, and the on-axis measurements were done near slack tide. The tungsten carbide and aluminum measurements were conducted mid-ebb tide. The apparent range in on-axis alongship angles over time was about $\pm 0.5^o$ for the aluminum and copper spheres and $\pm 1^o$ for the tungsten carbide sphere. The range of on-axis athwartship angles was approximately $\pm 1.5^o$ for the tungsten carbide and copper spheres and about $\pm 0.75^o$ for the aluminum sphere.

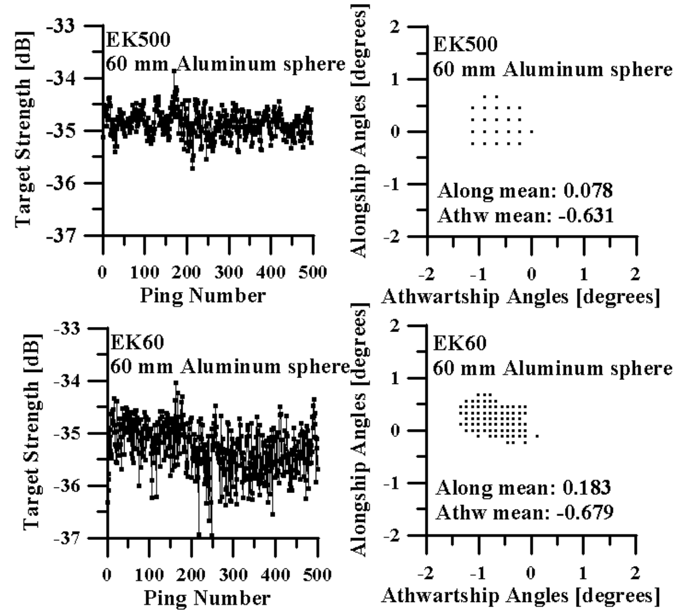

Figure 6. Time series (left side) and angular locations (right side) for on-axis measurements of a 60-mm-diameter aluminum sphere. Five hundred pings were collected with the EK500 (upper panels) and the EK60 (lower panels). The mean alongship and athwartship angles are given. Echo strength was compensated (equation (1)) for angular location in the beam ('compensated', split-beam target strength).

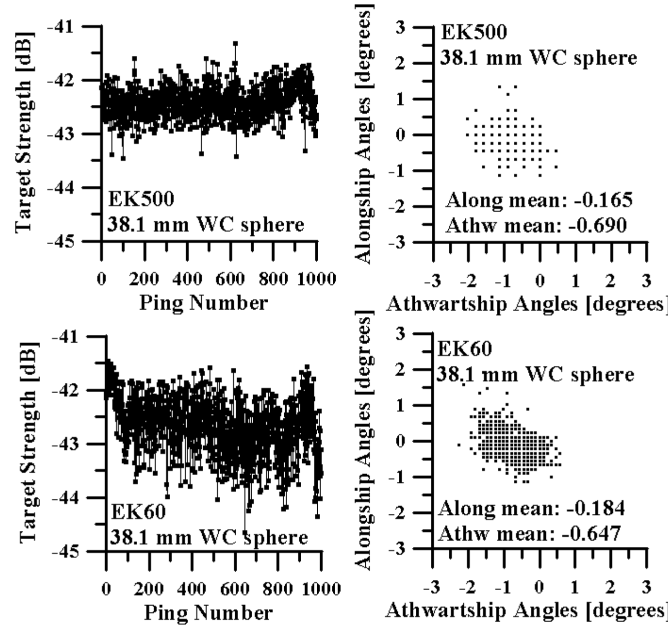

Figure 7. Time series (left side) and angular locations (right side) for on-axis measurements of a 38.1-mm-diameter tungsten carbide with 6% cobalt binder sphere. One thousand pings were collected with the EK500 (upper panels) and the EK60 (lower panels). The mean alongship and athwartship angles are given. Echo strength was compensated (equation (1)) for angular location in the beam ('compensated' split-beam target strength).

A relationship between the variability in angular locations and target strengths may exist as the tungsten carbide sphere had the greatest split-beam target strength and angle variability among the

spheres. This relationship may be tidal stage dependent, but is difficult to discern due to the lack of a systematic method to measure the tidal current effects. Even though the angular variability was different among spheres, mean alongship and athwartship angles were similar among trials, suggesting a potential alignment error with the apparatus. The issue of apparatus alignment errors versus split-beam target localization errors will be addressed in a planned trial.

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REFERENCES

[1] Foote, K.G., H.P. Knudsen, G. Vestnes, D.N. MacLennan, and E.J. Simmonds. 1987. Calibration of acoustic instruments for fish density estimation: A practical guide. ICES Coop. Res. Rep. 44.

[2] MacLennan, D. N. 1990. Acoustical measurement of fish abundance. J. Acoust. Soc. Am. 87(1): 1-15.

[3] Foote, K.G. 1983. Maintaining precision calibrations with optimal spheres. J. Acoust. Soc. Am. 73: 1054-1063.

[4] Foote, K.G. 2001. Calibrating a narrowband 18 kHz sonar. *Oceans 2001 MTS/IEEE Conference Proceedings*, vol. 4, pp. 2503-2505.

[5] Bodholt, H., N. Nes, and H. Solli. 1989. A new echo sounder system. Proc. Inst. of Acoustics. 11(3): 123-130.

[6] Jech, J.M., K.G. Foote, D. Chu, and S.P. Liberatore. Comparing two scientific echo sounders. *Oceans 2003 MTS/IEEE Conference Proceedings* (these proceedings).

[7] Doherty, K.W., T.R. Hammar, and K.G. Foote. 2002. Transducer mounting and rotating system for calibrating sonars in a sea well. *Oceans 2002 MTS/IEEE Conference Proceedings*, pp. 1407-1410.

[8] Jech, J.M., W. Michaels, W. Overholtz, W. Gabriel, T. Azarovitz, D. Ma, K. Dwyer, and R. Yetter. 2000. “Fisheries acoustic surveys in the Gulf of Maine and on Georges Bank at the Northeast Fisheries Science Center”, in *Proceedings of the Sixth International Conference on Remote Sensing for Marine and Coastal Environments*, 1-3 May, Charleston, South Carolina, USA. Veridian ERIM International, Ann Arbor, Michigan, USA.

[9] Demer, D.A., M.A. Soule, and R.P. Hewitt. 1999. A multiple-frequency method for potentially improving the accuracy and precision of *in situ* target strength measurements. J. Acoust. Soc. Am. 105(4): 2359-2376.

[10] Foote, K.G. 1982. Optimizing copper spheres for precision calibration of hydroacoustic equipment. J. Acoust. Soc. Am. 71(3): 742-747.

[11] SonarData Pty Ltd. GPO Box 1387 Hobart, Tasmania, Australia. (www.sonardata.com).

[12] Foote, K.G., H.P. Knudsen, R.J. Korneliussen, K. Roang, and P.E. Nordbø. 1991. Postprocessing system for echo sounder data. J. Acoust. Soc. Am. 90(1): 37-47.